NOTE ON THE ORIGIN OF "KEROSENE SHALE."

By T. W. Edgeworth David, B.A., F.G.S.

(Plate xviii.)

Introduction.—The so-called kerosene shale of New South Wales has been more appropriately termed Torbanite by the late Rev. W. B. Clarke.*

Professor Liversidge has also adopted the same name for it, remarking that the oil which it contains is probably not kerosene, and that the fracture in most cases is conchoidal and not shaly, the only exception to the latter rule being the small patch of oil shale formerly worked at America Creek, near Wollongong.†

The first mention of the discovery of kerosene shale, according to Liversidge *(loc. cit.)*, is that made by P. Cunningham, Surgeon, R.N., in a book entitled, "Two Years in New South Wales," published in London in 1827, where he describes its occurrence near Bathurst. Since that date kerosene shale has been proved to exist in many localities in this colony, of which the most important are the following:—Colley Creek, near Murrurundi and Greta in the Northern Coal-field, and in the same field in the *Greta Coal Measures*, at Homeville, near Stony Creek, West Maitland, it is represented by a seam of cannel coal; Hartley, Blackheath, Katoomba, Mt. Victoria, Mt. York, Burragorang, Wallerawang, Capertee, Bathgate in the Western Coal-field; Joadja Creek in the South-western Coal-field, and Mount Kembla, America Creek near Wollongong, and the head of the Clyde River in the Southern Coal-field.

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* Remarks on the Sedimentary Formations of New South Wales, Sydney, 1878, p. 66.

†Minerals of New South Wales, &c., by A. Liversidge, M.A., F.R.S., London. Trübner & Co., 1888, pp. 145-153.

The kerosene shale at each of these localities is believed by Mr. C. S. Wilkinson, F.G.S., the Director of the Geological Survey, to occur in the *Lower Productive Coal Measures*, otherwise known as the *Greta Series*, of Permo-Carboniferous age, and this fact first recognised by Mr. Wilkinson may prove a valuable help in the correlation of the different Coal-fields of New South Wales.

Occurrence.—Kerosene shale is developed in isolated patches for the most part near the edge of the basin of the *Lower Productive Coal Measures* of New South Wales. In certain coal seams it is associated with the coal, and occasionally passes rather suddenly into ordinary bituminous coal, Mr. C. S. Wilkinson having observed one instance where the transition occurred in the space of three feet.

The change from kerosene shale into bituminous coal can be traced vertically in the seam as well as horizontally. Mr. W. A. Dixon, F.I.C., F.C.S., in a paper read before Section B. of the Australasian Association*, calls attention to the fact that at Joadja there are three distinct layers in the kerosene shale seam, a lower layer of splint coal, a middle layer of kerosene shale, and an upper layer of good bituminous coal, and remarks (*loc. cit.*), "It is evident that the differences in the three layers in this seam cannot be ascribed to any other causes than an originally radical difference in the vegetation forming them."

In other cases, however, these lenticular patches become stony near the margins, and pass into a very fine-grained black carbonaceous clay shale, having a splintery conchoidal fracture. These patches vary in extent from a few square feet to perhaps over a square mile, and in thickness from a few inches to five feet. The kerosene shale, though at first sight it appears to be massive, is in reality minutely laminated, as may be observed if the weathered outcrops of the deposit be examined. The laminæ occasionally show imprints of *Glossopteris* and *Vertebraria.* The former are

* Proceedings of Australasian Association for the Advancement of Science. First Session, 1888, p. 127.

found to conform to the planes of lamination, whereas the latter, as I am informed by Mr. C. S. Wilkinson, are almost invariably found at Joadja to lie with their longest axes at right angles to the planes of bedding, so that they must have been growing in an erect position at the time that the kerosene shale was being formed. Professor Liversidge also mentions this fact (*loc. cit.* p. 146). Mr. Wilkinson also informed me that the substance of the *Vertebraria* in these shales is usually found to be converted into jet.

Where of an inferior clayey character the shale contains great numbers of spherical bodies sprinkled through it, about the size of a small pin's head, and about 1-50th to 1-40th of an inch in diameter. In places these pin-head bodies are represented by hollows of about the same size, or a trifle smaller, partly filled with a brown resinous-looking powder. This has been observed by the author at Iron Creek, near Mittagong, and also in the core from the recently completed bore at Woodford, in the Blue Mountains.

At the Homeville colliery, at Stony Creek, near West Maitland, a band of fire-clay occurs in association with the main seam of cannel coal, which here represents the kerosene shale; and this fire-clay contains spherical bodies about 1-40th of an inch in diameter in such abundance as to constitute about $\frac{1}{4}$th of the whole rock. They consist of earthy ochreous limonite, and become magnetic on being heated to bright redness in the blowpipe flame. Microscopic sections, however, prepared at the Department of Mines, and exhibited by kind permission of the Minister for Mines, show that these bodies, which at first sight might be supposed to be minute concretions, are probably minute fossils. Their spherical shape suggests that they may belong to sporangia, or seeds, or possibly large spores. They appear to consist of three parts—an amorphous nucleus, surrounded by a thick zone having more or less of a fibrous radial structure, which last is encased in a narrow opaque ring which forms the outer envelope of these bodies. Were they concretions there would probably be less uniformity in their size, and they would be not so much indented, as they are, into the fossil leaves with which they are associated.

Mr. W. A. Dixon (*loc cit.* p. 133) requotes a statement of his from Professor Liversidge's "Minerals of New South Wales" with regard to a coal from Mittagong, which the author knows to be intimately associated with the kerosene shale, to the effect that "the bright lines of fracture were marked by numerous lens-shaped cavities 00·5 to 0·10 inch in greater diameter, generally filled with a brownish pulverulent carbonaceous matter. These were apparently the impressions and remains of seeds, and they showed traces of a dense cortical layer." Mr. C. S. Wilkinson informs the author that he has observed numbers of similar sporangia or seeds associated with, he thinks, the Lower Lithgow seam at Bowenfels. Microscopic sections of the kerosene shale itself show that it consists largely of numerous flat, elongated, and round or oval particles, some of which at any rate may be referred to spores, spore-cases, or seeds.

Fossil wood is conspicuously absent from the *Lower Coal-Measures* in which the kerosene shale occurs. A few fragments, however, are occasionally met with near Maitland in the Ravensfield Sandstone of the *Lower Marine Series*, which underlies, and in some of the beds of the *Upper Marine Series*, which overly the *Lower Coal Measures.* There is no evidence, however, of the existence of large roots or stools of trees in the underclays of the kerosene shale or cannel coal, such roots as do exist being somewhat minute.

The following is a section by Mr. J. Mackenzie, F.G.S., of the kerosene shale seam at Joadja, near Mittagong, in this colony* :—

(Roof) Conglomerate.	Ft.	In.
Bituminous Coal	0	8
Boghead Mineral	1	0
Indurated Clay	0	1
Boghead Mineral	1	0
Coal and Shale (hole in this)	1	6

* Mineral Products of New South Wales, &c., and Description of the Seams of Coal Worked in New South Wales, by John Mackenzie, F.G.S., 1887 edition, p. 176.

With this it may be of interest to compare a descending section of the Torbanehill seam in Scotland by Thomas Stuart Traill, M.D., F.R.S.E.*

1. "A thick roof of sandstone.
2. *Faeks*, a crumbling shale = 4 inches in thickness.
3. *Cement*, a mixture of shale and poor ironstone = 3 inches.
4. *Bitumenite*, which in this pit at the face = 1 foot 4 inches in thickness (elsewhere 1 foot 11 inches, T.W.E.D.).
5. Fine ironstone from 2 inches to $\frac{1}{2}$ inch.
6. Bituminous shale often containing tabular masses of good ironstone = 2 inches.
7. An inferior coal = 7 inches. These four last-mentioned beds are all raised with the Bitumenite, and together measure 2 feet 3 inches in thickness.
8. Coal much mixed with shale, here called *foul coal*, about 2 feet 4 inches.
9. Fireclay."

The "Bitumenite" above is a synonym proposed by Dr. Traill for Torbanite.

On p. 10 *(loc. cit.)* he states that large *Stigmariæ* occur in the Torbanite, one as thick as a human body, and also that no real organic structure was visible in the Torbanite, but numerous globules of a pale yellowish matter. In the same publication, p. 176, Dr. John Hughes Bennett, M.D., F.R.S.E., describes minute transparent bodies in the Torbanehill Mineral having a radiate crystalline appearance, and being from $\frac{1}{200}$th to $\frac{1}{4000}$th of an inch in diameter. He states (*loc. cit.* p. 181) that these yellow masses in the Torbanehill Mineral are a "bitumenoid or resinoid substance, imbedded in earthy matter;" and also that "We could nowhere discover in them any trace of cell wall or contents. . . . Numbers of them present no envelope or definite boundary."

* Trans. Roy. Soc. Edinburgh, XXI. Part 1, p. 8.

Chemical Composition—Mr. W. A. Dixon in his above quoted papers, page 135, gives the following as an analysis of the best Joadja shale :—

Carbon	75·32
Hydrogen	12·05
Oxygen	5·49
Nitrogen	0·28
Sulphur	0·31
Ash	6·55

On the preceding page of the same paper, Mr. Dixon says, "It has been suggested by some one that the shales are the products of resinous spores of some plant. From the persistent fatty products of distillation, I think resin must be abandoned, as resins pass more to aromatics. It appears to me more probable that shale comes from some oil or wax producing plant, more likely the latter, in view of the considerable yield of solid paraffin." On p. 137 of the same paper, Mr. Dixon states that "the organic matter of the shale is evidently a very stable body. It is almost absolutely insoluble in naphtha, carbon bisulphide and similar menstruæ."

Professor Liversidge states *(loc. cit.*, p. 145*)*—"The Hartley and Murrurundi shales are but slightly soluble, if at all, in alcohol, ether, carbon disulphide, petroleum or caustic potash, even when boiled ; but they gelatinise with boiling sulphuric acid, and evolve a sulphurous acid odour; with nitric acid they yield a yellow solution."

On p. 148 *(loc. cit.)*, the same authority gives the following analysis by himself of kerosene shale from Joadja Creek, and, amongst analyses of other similar minerals for comparison, one by How of the Torbanite, from Torbane Hill :—

Locality.	Moisture.	Volatile Hydro-carbons.	Fixed Carbon.	Ash.	Sulphur	Specific Gravity.
12. Joadja Creek, N.S.W.	0·04	82·123	7·160	10·340	0 337	1·229
25. Torbanite, Torbane Hill...	......	71·17	7·65	21·18	......	1·170

Previous Theories about its Origin.

(1) *Drift Timber Theory.*—With reference to the origin of kerosene shale, the late Rev. W. B. Clarke* states that "it has unquestionably resulted from the local deposition of some resinous wood, and passes generally into ordinary coal, many portions of the same bed in the Illawarra mines exhibiting the unmistakable features of the latter and the impress of fronds of *Glossopteris* as plainly as they are shown on ordinary coal shale." On the following page Mr. Clarke states, "presuming that the origin above suggested is correct, viz., the occasional occurrence in the ancient deposits of trees of a peculiar resinous constitution, there is no anomaly in finding in one spot a mere patch amidst a coal seam (as is the case at Anvil Creek on the Hunter River), or thick-bedded masses of greater area as in the coal seams of Mount York, or of American Creek in the Illawarra, depending on the original amount of drift timber." This theory is the one at present most generally accepted.

(2) *Distillation Theory.*—The late Examiner of Coalfields, Mr. Wm. Keene, F.G.S., was of opinion that kerosene shale owed its origin to a natural distillation of the hydrocarbons from bituminous seams through the heat of igneous rocks intruded into the coal-measures subsequent to the formation of the coal-seams. He considered, therefore, that igneous rocks of later date than the coal-measures formed everywhere a necessary accompaniment to kerosene shale.

(3) *Oil-spring Theory.*—The late Professor Denton, when in Sydney a few years ago, suggested that kerosene shale was due to local outbreaks of oil-springs, which may have overflowed at the surface and saturated the peaty material in the coal-swamps for a considerable radius around the scene of the outbreak. This explanation, however, simply puts the difficulty back a stage, but

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* Sedimentary Formations of New South Wales, Sydney, 1878, p. 66.

does not remove it, as the obvious question at once suggests itself, What caused the oil-wells? and of this no satisfactory account can be given.

It might be argued that such oil-wells might have had an origin similiar to those of Trinidad, which are associated with the famous Asphaltum Lake of La Brea. At Trinidad, however, the oil and asphaltum is considered by Messrs. S. P. Wall and J. G. Sawkins, F.G.S.,* to have originated from the alteration *in situ* of ligneous deposits, together with, perhaps, a slight admixture of animal material, especially shells. They consider the Asphaltum Lake of La Brea, which has a superficial area of 99⅓ acres, and is estimated to contain about 3,168,000 tons of bitumen (the average depth being supposed to be 20 feet), to have resulted simply from a segregation and concentration of the bitumen in local depressions in the asphaltic sands and shales.

The same authors state (*loc. cit.* p. 144) :—"The conversion from the ligneous into the bitumineous structure may be seen in any stage, from the first deposit (usually parallel with the fibres) to the total obliteration of organic texture, when nothing but the external form of the wood remains." They conclude that asphaltum has been formed from vegetable material by direct conversion at the ordinary temperature. The same stratum may be lignitic at one point, and asphaltic at another, the difference being attributed to the different chemical reactions which have taken place, the tendency being for lignite to be formed, where the deposit is of a pure carbonaceous nature, and asphaltum, where a large proportion of earthy matter exists. The first stage in the process of conversion of woody matter into asphaltum consists in the formation of asphaltic oil ; this oil rises in springs from comparatively shallow depths. The residue after the separation of this oil is usually the ordinary asphalt.

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* "Memoirs of the Geological Survey of the West Indies." Part I. "Report on the Geology of Trinidad." By S. P. Wall and J. G. Sawkins, F.G.S., 1860, pp. 143-147.

Vegetable Secretion Theory.—This theory was advanced by Mr. W. A. Dixon in his paper already quoted (pp. 135 and 136), and the similarity in the chemical composition of some waxes of living plants to that of kerosene shale, as Mr. Dixon points out, lends some weight to this argument.

It may be not out of place here to mention that Mr. Hamlet, F.C.S., the Government Analyst, stated at the last meeting of the Royal Society that the fact had lately come under his notice that a considerable quantity of oil had lately been observed to be floating on the surface of the reservoir at the waterworks at West Maitland. This oil, in Mr. Hamlet's opinion, was produced by a small aquatic plant, *Spirogyra* or *Protococcus*, but he was not prepared to say whether the oil was secreted by the plant, or whether it was connected with fructification. He was inclined to the former opinion.

Coorongite Theory.—The author is informed by Mr. C. S. Wilkinson that he believes that it has been suggested that kerosene shale may have had an origin similar to that of the *Coorongite* found at Coorong, in South Australia. The author, however, has been unable to find any reference to such suggestion.

Coorongite is described by W. T. Thiselton Dyer, B.Sc., F.L.S.,* as "a peculiar indiarubber-like material, . . . the history and origin of which seem likely to become matters of as great controversy as the true nature of the Torbane Hill Mineral. In appearance it consists of sheet-like masses somewhat less than an inch in thickness, and with more or less scattered sand-grains adhering to their surface. It occurs at a place called Coorong, whence it is brought to Adelaide. The country in the neighbourhood is described as consisting of limestone ridges and scrub without grass. The Coorongite, as it has been named, is confined to a depressed portion of the district, the bottom of which is sandy and grass-covered ; it occurs on the banks forming the

* "On a Substance known as Australian Caoutchouc." Journal of Botany, 1872, pp. 103, 104.

margins of the depression, and also on the sides of island-like elevations which are scattered about it." On page 104 (*loc. cit.*) he states, "Another writer in the *Register* (May 8th, 1866) describes thin sections as 'exhibiting under the microscope, especially if moistened with a solution of caustic potash or benzole, a granular and cellular structure with entangled fibres resembling the fibres of decayed fungi.' Mr. Berkeley has also, as he informs me, been struck with this pseudo-cellular structure. Mr. Archer, the Secretary of the Dublin Microscopical Club, to whom I submitted a fragment for examination, gives, I think, the true explanation of this appearance. He writes to me in a recent letter to the following effect:—'I think the substance in question is certainly organic—some kind of gum with accidental things imbedded, such as bits of vegetable tissue, some confervoid or fungal threads, and the like. Once I saw a *Cymbella* in the material, but I never could find the same place again. The matrix appears to possess a certain amount of *quasi* cellular appearance by reason of streaks running here and there in a *quasi* reticulated manner. Of course, in the act of making the section, the knife leaves a number of superficial streaks which one must throw overboard.' The structure of the matrix noticed above may doubtless be attributed to a physical fibrillation due to the mere shrinking and hardening of the substance. That it must have been in a soft, if not fluid state, is evident from the miscellaneous collection of cryptogamic *reliquiæ* which different microscopists have detected in it. Their miscellaneous character is a sufficient proof that their presence is adventitious. As to the origin of the substance, opinions are the most discordant possible. The suggestion which occurred to Mr. Berkeley that it is the residue of some cryptogamic plant, is, at first sight, very plausible. One can imagine such a residue being formed by *Bromicolla aleutica*, which forms in the Aleutian Isles a layer two feet thick of a Nostoc-like substance, covered with a gramineous vegetation. One can imagine it also to result from the drying up of a lake covered with *Hoomonema fluitans*, the 'vegetable turtle-fat,' described by

Dr. Seeman as a jelly-like mass several feet thick, with a tall species of sedge growing in it. The following analysis made by Dr. Bernays discountenances, however, this theory entirely.

He found :

Moisture	·4682
Carbon	64·7300
Hydrogen	11·6300
Ash	1·7900
Oxygen and unestimated matters....	20·3768

Any residue left by a Cryptogam (assuming, of course, that no extensive change of composition had taken place in it, except the loss of water) would contain about 50 per cent. oxygen, or far more than the *whole* of the unestimated matter put down above; it would also contain much less hydrogen. It may, therefore, be safely concluded that no cryptogamic growth could have produced a substance which is practically a hydro-carbon and not a carbo-hydrate."

Professor Thiselton Dyer concludes that coorongite may be the oozing or secretion of some plant like the grass-tree *(Xanthorrhœa)* or it may have been formed from petroleoid springs. The diatoms found in the coorongite are all freshwater species, as the author is informed by Mr. J. J. Fletcher, M.A., B.Sc., to whom he is indebted for the above reference to Professor Thiselton Dyer's paper, and also for the following reference to a description of the diatoms associated with coorongite.*

Mr. R. Etheridge, jun., has also kindly supplied the author with the following references to coorongite.†

* Quarterly Journal of Microscopical Science. Vol. XIII. New Series, p. 211. "The diatoms in the Australian Caoutchouc, &c," by the Rev. E. O'Meara.

† Coorongit, a New Australian Mineral Product. Baird's Annual Record of Science and Industry for 1872, p. 134.

Coorongit. Das Australische Kautschuk Coorongit. Der Naturforscher, 1872, V. No. 23, p. 186.

The author has been unable to get access to the two last-mentioned works, but these references may perhaps be of use to others.

The many points of resemblance between coorongite and kerosene shale may serve as an excuse for the author having introduced so lengthy a quotation as to its nature and probable origin. So long, however, as these remain a mystery, their exact bearing, if any, on the origin of kerosene shale, must remain in abeyance.

Arguments against Drift Timber Theory.—(1) Had kerosene shale been formed from rafts of resinous trees, which became macerated at the spots where we now find kerosene shale, it is unlikely that the maceration should in every case have been so thorough and complete as not to leave a vestige of woody structure behind. At Trinidad, for instance, as already related, the wood in the asphaltic deposits exhibits every gradation of change from the ligneous into the bitumenous state, so that if the whole deposit were buried under thick sediments for a long geological period until it became completely fossilized, and were afterwards re-exposed by denudation, there would be ample proof of the formation of bitumen from woody matter in the fragments of the undecomposed and partially decomposed woody material in the rocks associated with the bitumen, and the latter would also contain pseudomorphs in bitumen after the original individual fragments of wood. In the case, however, of the kerosene shale seams of this colony fragments of fossil wood are rarely found in the strata immediately associated with the kerosene shale seams.

(2) It is difficult to understand how *Glossopteris* leaves could have become so delicately interleaved with the laminæ of the kerosene shale, or the *Vertebraria* stems have maintained their erect position in the kerosene shale, supposing it to have originated from a mass of drift wood. Such leaves would in the case supposed have been chiefly restricted to the top of the mass, and would not have been evenly distributed through it, as they are now found.

(3) The resins in such trees, during such supposed maceration, would be liable to separate out in places into small irregular

patches and lumps, like the retinite in the altered brown coal of Invercargill and Kawa Kawa, Bay of Islands, New Zealand, but such do not as a rule occur in the shale.

(4) Drift timber would be sure to carry fragments of rock or lumps of earth entangled in its roots, and these would be liable to be imbedded in the shale, during the process of maceration, but this is not found to be the case.

(5) The results of the decomposition of resinous trees would probably be to produce some true resin, but from the reports above quoted of Mr. Dixon and Professor Liversidge, kerosene shale is not appreciably soluble in alcohol, ether, or bisulphide of carbon, and it certainly would have been partly soluble had it contained resin in large proportion.

Arguments against Theory of Distillation by Intrusive Igneous Rocks.—(1) In some cases, as at Greta, kerosene shale has been found far removed from intrusive igneous rocks.

(2) At Joadja, if the shale had resulted from distillation, the seam would have had a tolerably uniform composition, instead of being separated into three distinct layers.

(3) Oil would be found in the crevices and interstices of the rock wherever it is at all porous. But this has not been observed.

Arguments against Oil-spring Theory.—These would be the same as those already advanced against *drift-timber theory*, with the exception of (4) and (5), and with the additional objection that there would be no apparent source for the oil-springs.

Arguments against Vegetable Secretion Theory.—No valid arguments have occurred to the author against this theory, with the exception that it does not fully account for the very lenticular character of the shale, nor from its development being chiefly confined to the edge of the coal basin. It appears, however, by far the best of the theories already advanced, and may be the correct one, though the author thinks that there is more evidence in favour of his own theory.

Arguments for and against Coorongite Theory.—The origin of Coorongite being not yet understood, it is useless to speculate as to a possible similar origin for the kerosene shale, though the latter certainly possesses some striking points of resemblance to the former, especially if allowance be made for the elimination of oxygen, which would take place in Coorongite were that mineral subjected to such prolonged conditions of heat and pressure as the kerosene shale has undergone.

Suggested Theory of Kerosene Shale having been formed from Sporangia, Spores, Pollen, or Seeds.—The minute lamination of kerosene shale, and the uniform distribution throughout it of the minute resinous-like particles, taken in conjunction with the fact that fossil leaves are regularly interlaminated with the shale, especially where it is at all inferior, lead the author to infer that the finely divided state of the kerosene shale was of primary and not of secondary origin. If the resinous-like particles were originally in a finely divided state, the most natural assumption is that they were spores, sporangia, pollen, or seeds. A microscopic examination of the clay shales associated with the cannel seam at Homeville shows them to contain abundant spherical bodies, about 1-30th of an inch in diameter, which are probably sporangia. Somewhat similar bodies are observable in inferior portions of the kerosene shale, and possibly even in purer varieties. It is possible, therefore, that the oily character of these shales may be chiefly due to the local accumulations of showers of minute spores or sporangia or seeds, with a certain admixture of peaty material from the swampy ground in which the coal was found.

What was the nature of the plants which supplied these small spherical bodies is at present unknown. Probably they did not belong to the genus *Glossopteris*, for had they been derived from a plant so universally distributed as this is throughout the *Lower Coal Measures*, kerosene shale would probably be less restricted in its occurrence than we now find it. Perhaps these minute bodies were derived from plants which grew on the hills which fringed the coal basin. This supposition would, if correct, explain the fact that kerosene shale is chiefly restricted to the edges of the coal basin. Wind blowing off the hills would be apt to carry with it spores from cryptogamic plants, and deposit them over the swampy flats of the coal basin, much in the same way that the pollen from the catkins of the fir is blown over the pine forests and lakes of Scotland, Scandinavia, and Canada, as described by Dr. John Davy.* Such deposits, even at the present day, frequently attain a thickness of half an inch. Where the pollen shower falls on earth it soon becomes mixed with the decayed vegetation and earthy impurities, but where it falls on the surface of lakes it floats for a while, then becomes water-logged and sinks to the bottom, where it would form a thin layer of inflammable material. If little or no muddy sediment were received into the lake, such an accumulation might go on from year to year until it had acquired a considerable thickness, and such light material as leaves of trees and needles of the fir would be liable to become interbedded with this deposit. Such a deposit, however, would not be uniformly pure, as every shower of rain would be sure to wash in a little sediment round the margin of the lake, and so render the pollen sheet clayey along such areas of sedimentation. Somewhat analogous to these pollen showers is the spore dust from tree-ferns, which is described by R. M. Johnston† as so filling the air at certain seasons in the fern-tree gullies of Tasmania, as to affect travellers with fits of sneezing while passing through such belts of spore-laden atmosphere.

Phenomena somewhat analogous to those of the pollen and spore showers would be likely to have obtained on a grander scale during the Permo-Carboniferous Period in Australia. Here and there around the margins of the low-lying swampy flats in which the coal was being found there would be likely to be shallow lakes devoid of vegetation, so that although the supposed

* Proc. Roy. Soc. Edinburgh, Vol. IV. p. 157 (1859). The author is indebted to Professor A. H. Green's Geology, Part I. p. 184 (1882) for this reference.

† Geology of Tasmania, by R. M. Johnston, F.L.S., &c., 1888, p. 138.

spore showers would fall with tolerable uniformity over the edges of the plains of the Greta coal-basin, only such portions of the showers as fell on the surface of the lakes would be fairly free from admixture with vegetation, and so would form, when they sank water-logged to the bottom, a tolerably pure inflammable deposit, with, of course, a certain amount of peaty material intermixed. Every one of the minute laminæ of the kerosene shale may therefore represent a spore shower, or a season of spore showers, so that it may have taken many hundreds of years to have admitted of the formation of a seam of kerosene shale five feet thick, as at Hartley. It is possible, however, that these laminæ may be simply due to superincumbent pressure, irrespective of individual spore showers, and they may therefore have no special chronological value. Subsequent to these supposed local accumulations of pure spore deposits in the shallow lakes of the Greta coalfield, there is evidence of sedimentation having set in again, which, before the close of the Permo-Carboniferous Period, buried the Greta coalfield in places under at least 6000 feet of strata. The great pressure and considerable heat consequent on the Greta coalfield being loaded with such a thickness of sediments would tend to efface the original sporaceous character of the lacustrine spore beds, especially in those areas where the deposit was so fine that the individual spores were in close contact with one another ; but where they were much intermixed with muddy sediment, the isolation of the individual spores would prevent their being agglutinated, so that it is chiefly to these impure varieties of kerosene shale that observation may be most advantageously directed with a view to seek further information as to the origin of the purer varieties.

Possibly the minute spherical bodies observed by the author in association with kerosene shale may be the spore cases of *Rhizocarps* allied to *Salvinia* of the present day, and so abundant in the bituminous Huron Shales of Ohio.

The origin of the kerosene shale of New South Wales from seeds or spores is stated by Mr. Dixon, in his paper above quoted, to have been advanced before by some one, but up to the present the author has not met with any reference to such a hypothesis. Mr. Dixon states, as an objection to the "Seed-and-spore-Theory," that kerosene shale is not of a resinous composition. If, however, the kerosene shale of New South Wales be analogous to the Tasmanite of the Mersey River Coal-field in Tasmania, which is of approximately the same geological age, it may be composed of sporangia or spores without being of resinous composition, as Mr. E. T. Newton, F.G.S., in describing the Tasmanite, or White Coal of Tasmania says* that the apparent resinous particles which microscopic examination proves to be sporangia, are in reality not resinous, as they are insoluble in alcohol, ether, or bisulphide of carbon. This objection is therefore partly if not wholly answered by the results of Mr. E. T. Newton's experiments.

If, therefore, kerosene shale is formed chiefly of sporangia, it has analogues in this Tasmanite, and in the well-known "Better-Bed" Coal Seam near Bradford, England, which latter, as described by Professor Huxley,† is chiefly made up of spore cases and spores.

Further light may be thrown upon the origin of kerosene shale by careful microscopic research, a means of study, which up to the present has never been systematically applied to the oil shales and coals of this colony.

The above theory is advanced by the author in a tentative manner, open to subsequent correction, and is chiefly based on his recent observation of the frequent association of abundant small spherical bodies like sporangia or seeds with the kerosene shales and cannel coals of this colony.

The author is indebted specially to Mr. John Waterhouse, M.A., of West Maitland, for kindly procuring him the specimens of sporangia (?) fireclay and cannel coal exhibited this evening, to Messrs. C. S. Wilkinson, R. Etheridge, Jun., and J. J. Fletcher, for many useful references and suggestions, and to Mr. P. T. Hammond of the Mines Department, for drawing the accompanying plate.

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* Geol. Magazine, 1875, Dec. 11, Vol. II., p. 339.

† Critiques and Addresses, pp. 94-97, 1873.

Appendix.

Since reading the above paper, with the exception of one or two references which have been subsequently added, the author has succeeded in preparing a good microscopic section of the kerosene shale from Joadja Creek. Examined under the microscope by transmitted light, the small spherical resinous-like bodies, of which the shale is chiefly composed, are seen to possess a decided organic structure, which appears to resemble that of the minute "pin-head" bodies of the carbonaceous clay shales at Hill Top, near Mittagong, and at Woodford in the Blue Mountains, but differs somewhat from that of the objects figured in the accompanying plate. Numerous aggregations of minute spindle-shaped or club-shaped bodies are seen to occur in each globule, and recall the appearance of zoospores in some forms of Algæ. It is just possible, therefore, that hereafter it may be found that these spherical bodies are to be referred to some variety of fresh-water Alga, which, like the *Volvocineæ*, consist of single gelatinous globules enclosing zoospores. In this case the lenticular deposits of kerosene shale would have their analogues in the deposits of "vegetable turtle fat" already referred to, and to accumulations of infusorial earth, and perhaps to the sheets of Coorongite, if the latter be of cryptogamic origin. At all events, in the present state of our knowledge, it may be asserted that kerosene shale was probably formed in lakes, and that it was formed from minute plant bodies, probably either sporangia or algæ. Mr. R. Etheridge, junr., has kindly promised to assist the author in investigating this question, and the author hopes that Mr. Etheridge and he will soon be able to communicate to the Society a joint paper on this subject.

EXPLANATION OF PLATE.

The circular bodies are pseudomorphs in limonite after sporocarps (?), and occur in yellowish-brown fireclay associated with the Fireclay Seam, which overlies the Cannel Coal Seam at the Homeville Colliery, near West Maitland. These sporocarps (?) average about one-fortieth of an inch in diameter.